# Evaluation of different management systems based on $CO_2$ and $N_2O$ emissions

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FINAL REPORT

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## 1. Introduction

Carbon-dioxide ($CO_2$) and nitrous-oxide ($N_2O$) are important greenhouse gases (GHG), both of them has natural and anthropogenic sources as well. Anthropogenic activity and its influence on soil surface are an important but uncertain component in GHG circulation processes and are in the spotlight from a scientific standpoint regarding climate change. Agricultural induced GHG emissions participate with 10-12 % of global anthropogenic GHG emission, so agriculture is one of the main source of GHGs (Smith et al., 2007). Agricultural activities in a crop production system like different tillage or fertilization practices influence soil physical and chemical characteristics such as soil water content, soil temperature, soil compaction or humus content which are the main driving factors of soil $CO_2$ and $N_2O$ emissions (Hursh et al., 2017, Bogunovic et al, 2017, Dencső et al., 2021). Thus, there is a growing need to use “good agricultural practices” to maintain soil health on arable land, to ensure food quality and crop yields, and to mitigate GHG emission.

Measurement of soil $CO_2$ emission has a more than 100-year-old history, but standardized methodology is still lacking (Drewer et al, 2016, O’Dell et al, 2015). Measuring soil $N_2O$ emission is even a more challenging issue, since temporal and spatial variation of $N_2O$ emission is extremely high (Hénault et al, 2012). Thus, contradictory results can be found in scientific literature about the effect of different soil tillage practices on GHG emissions. Few researches report higher $CO_2$ emission in ploughing (Huang et al., 2018, Yeboah et al., 2016), other investigations conclude higher $CO_2$ emission in reduced or no-tillage tillage treatments (Alvarez et al, 1998, Lognoul et al., 2017) and it is also existing not to find any significant difference. Quite a few researches report higher $N_2O$ emissions of reduced or no-tillage treatments compared to tilled fields, certains conclude opposite findings, or no significant differences (van Kessel et al., 2013).

So the main aim of the proposed work was to evaluate different agricultural practises, especially different tillage applications on soil $CO_2$ and $N_2O$ emission and their main driving factors.

## 2. Materials and Methods

### 2.1 Laboratory experiments

To investigate the underlying processes of GHG emissions in more controlled environment, we set up the different laboratory experiments. The main aim of these experiments was to study the effect of tillage, fertilizer doses, soil water content and soil temperature on soil $CO_2$ and $N_2O$ emissions. For this purpose we prepared different laboratory set up where the main aspect was to use undisturbed soil columns to keep the original soil structure for the investigations. Further advantage of these experiments is that in the lab soil water content and soil temperature could be kept in a certain value. More details about the experiment set up is shown in Dencső et al., 2021.

### 2.2 Field scale experiment

Our field measurements were carried out in a long-tem (established is 2002) tillage experiment at MATE’s (former Szent István University) Józsefmajor Experimental and Training Farm, Heves County, Hungary (47 41′31.7″ N 19 36′36.1″ E, 110 m a.s.l). The soil is Endocalcic loamic chernozem, which is a dominant soil type in the region of the study. The climate is typical continental type with 560 mm average annual precipitation and 10.3 °C mean annual temperature. The experiment consists of six different tillage treatments in a randomized design, three of them are (mouldboard ploughing -P, no-tillage -NT, shallow cultivation -SC) in the focus of our investigations (Figure 1).  Each tillage treatment had an area of 10 × 105 m in four replicates.

Figure 1. The three investigated tillage treatments: Shallow cultivation (SC), ploughing (P) and no-till (NT)

In the experiment, crop rotation and adaptive fertilization were used annually. After harvest plant residuals were left on the surface as mulch, and straw was mixed with the soil during tillage operations. Management event and fertilizer doses and dates are shown in Table 1.

Table 1. Management events and fertilizer doses between 2015 and 2020 in the experimental site

| **Year** | **Crop type** | **Date of fertilization** | **Applied N fertilizer doses** | **Date of sowing** | **Date of harvest** | **Date of tillage** |
|---|---|---|---|---|---|---|
| 2015 | Winter wheat (*Triticum aestivum* L.) | 07/10/2014<br>16/04/2015<br>29/05/2015 | 28.5 kg ha$^{-1}$<br>35 kg ha$^{-1}$<br>15 kg ha$^{-1}$ | 08/10/2014 | 08/09/2015 | 02/10/2014 |
| 2016 | Maize (*Zea mays* L.) | 28/10/2015<br>16/04/2016 | 42 kg ha$^{-1}$<br>72 kg ha$^{-1}$ | 18/04/2016 | 24/10/2016 | 28/10/2015 |
| 2017 | Winter oat (*Avena sativa* L.) | 27/10/2016<br>03/03/2017 | 24 kg ha$^{-1}$<br>100 kg ha$^{-1}$ | 01/11/2016 | 12/07/2017 | 28/10/2016 |
| 2018 | Soy *(Glycine max)* | 20/03/2018 | 60 kg ha$^{-1}$ | 26/04/2018 | 17/09/2018 | 11/09/2017 |
| 2019 | Winter wheat (*Triticum aestivum* L.) | 10/10/2018<br>11/02/2019 | 20 kg ha$^{-1}$<br>30 kg ha$^{-1}$ | 10/10/2018 | 18/07/2019 | 10/10/2018 |
| 2020 | Winter oat (*Avena sativa L.*) | 02/10/2019<br>02/20/2020 | 20 kg ha$^{-1}$<br>60 kg ha$^{-1}$ | 09/10/2019 | 15/07/2020 | 16/09/2020 |

### 2.3 $CO_2$ and $N_2O$ measurements

For measuring soil $CO_2$ and $N_2O$ emission we used chamber technique during the five years of the project but some methodology development was carried out after the third year. In the first years we used static chambers and collected air samples into vacuumed vials from the headspace of chambers right after closure and twenty minutes later as well. $CO_2$ and $N_2O$ concentration of the samples were analyzed with gas chromatograph. More details about the methodology can be found in Tóth et al., 2018a, Horel et al., 2018b. In 2017 and 2018 two portable gas analyzer was bought with the support of another projects and we started to use them in this project as well. EGM-5 (PP System) is used for measuring $CO_2$ emission and Picarro G2508 for measuring $N_2O$ emission. In 2017 we used parallel the old method and de new devices, than compared the results (Dencső et al. 2018ab).The new measurement methodology of these devices is presented in, Tóth et al., 2020 and Dencső et al., 2021. In the experimental site $CO_2$ and $N_2O$ emission was measured in the chosen treatments in 7 and 3 replicates, respectively.

## 2.4 Ancillary measurements

To better understand the temporal and spatial variability of soil $CO_2$ and $N_2O$ emission we measured several soil physical and chemical parameters in the experimental site. We installed soil water content (SWC) and soil temperature (Ts) sensors (5TM Decagon Devices Inc., Pullman, WA, USA) at 4 different depths in the sampling area. Also meteorological data were collected nearby the experiment. Bulk density, pF values, soil organic carbon (SOC) content, the main N forms as $NH_4^+$ and $NO_3^-$ and total N (TN) content were also measured yearly. The main plant characteristics as LAI, stem diameter, root-and shoot biomass was also determined at the main plant growth stages. Detailed information are shown in Tóth et al., 2018a.

## 2.5 Modeling

The first step in our modeling work was to select the model that fits best to our purposes. There are numerous considerations to be accounted for, when simulation modeling based studies are designed, and the actual simulation models or model packages are chosen (Waveren et al., 1999; Farkas and Hagyó, 2010). The outcome of a particular simulation based study is heavily dependent on – besides the model itself - the quality, resolution and amount of the input data available and used, the quality and extent of the expert knowledge about locally prevailing conditions, as well as the validity of any assumptions that are inevitably made while parameterizing the model (Waveren et al., 1999). Therefore, it is important to test the model's relevance for the study area and to find the balance between model's resolution both spatially and temporally vs. the resolution and availability of the data, model simplicity and ease of use and the experts' familiarity with the given simulation model(s). Saloranta et al. (2003) established a set of operational and functional selection criteria for mathematical models designed for simulating hydrological and biogeochemical processes in the terrestrial and aquatic ecosystems. These criteria, the so-called "benchmark-criteria" can also guide potential model users in selecting the appropriate model for use in other areas as well. The benchmark criteria are presented in the form of 14 questions – with a 3-tier response system – through which each model can be evaluated. During our modeling work we used these criteria to choose the best model solution. The second step was to set up the Hydrus-1 D model for the study site. To achieve this goal we evaluated the applicability of the Hydrus-1D model for simulating the differences in the soil water and heat regimes in different soil tillage systems than we tested the applicability of the model for simulating carbon-dioxide flux from the P and NT tillage systems, which correspond to the most and least disturbing mechanical disturbance.

Model performance was evaluated using three statistical types of metrics, each capable of evaluating somewhat different aspects of the simulations: the Nash-Sutcliffe model efficiency coefficient (NS), the regression coefficient ($R^2$) and the bias percentage (PBIAS).

The Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970) is a dimensionless, normalized statistic that determines the magnitude of the residual variance relative to the variance in the measured data. The Nash-Sutcliffe efficiency ranges from $-\infty$ to 1; improved model performance is indicated as the NS approaches 1, while a value of zero or negatives indicate that simulated values are no better than the mean of observed values. NS is calculated as:

$$NS = 1 - \left( \frac{\sum_{i=1}^{n} (Q_i - Q_i')^2}{\sum_{i=1}^{n} (Q_i - \bar{Q})^2} \right)$$

where *Qi* is the measured value (soil water content or soil temperature), *Qi’* is the simulated value, *Q* is the average measured value, and *n* is the number of data points.

The regression coefficient ($R^2$) is a standard regression type metric that has been widely used for model evaluation in literally every natural science. The $R^2$ value describes the degree of collinearity in the measured and simulated data. $R^2$ ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable. $R^2$ is calculated as:

$$R^2 = \frac{\left[ \sum_i (Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s) \right]^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2}$$

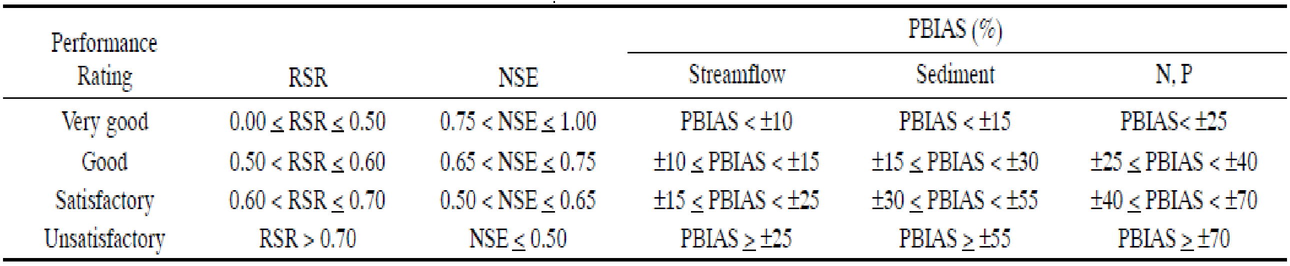
where m stands for measured, s indicates simulated, and all other notations are as for NS (above).

Percent bias (PBIAS, %) is an error index, that indicates the average tendency of the simulated data to be greater or smaller than the corresponding observed data. The optimal value of PBIAS is 0, small absolute values are indicating accurate model simulation. Positive values indicate model underestimation, and negative values indicate model overestimation (Gupta et al., 1999). In our study, PBIAS was calculated for the amount of water in the soil, as temperature sums have no physical meaning in this sense. PBIAS is calculated as:

$$\mathrm{PBIAS} = \left[ \frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^{n} (Y_i^{obs})} \right]$$

Using a combination of performance indicator types helps in obtaining a robust idea on the performance of a simulation model. Ideally, one obtains high NS and $R^2$ and low PBIAS, but it is rarely this simple in practice. While there is no consensus on specific coefficient values for the daily time step, we present the performance ratings for monthly simulations (Table 2), as suggested for the hydrological and biogeochemical models by Moriasi et al. (2007).

Table 2: General performance ratings for simulations at the monthly time step (Moriasi et al., 2007)



| Performance Rating | RSR | NSE | PBIAS (%) | | |
|---|---|---|---|---|---|
| | | | Streamflow | Sediment | N, P |
| Very good | $0.00 \le RSR \le 0.50$ | $0.75 < NSE \le 1.00$ | $PBIAS < \pm 10$ | $PBIAS < \pm 15$ | $PBIAS < \pm 25$ |
| Good | $0.50 < RSR \le 0.60$ | $0.65 < NSE \le 0.75$ | $\pm 10 \le PBIAS < \pm 15$ | $\pm 15 \le PBIAS < \pm 30$ | $\pm 25 \le PBIAS < \pm 40$ |
| Satisfactory | $0.60 < RSR \le 0.70$ | $0.50 < NSE \le 0.65$ | $\pm 15 \le PBIAS < \pm 25$ | $\pm 30 \le PBIAS < \pm 55$ | $\pm 40 \le PBIAS < \pm 70$ |
| Unsatisfactory | $RSR > 0.70$ | $NSE \le 0.50$ | $PBIAS \ge \pm 25$ | $PBIAS \ge \pm 55$ | $PBIAS \ge \pm 70$ |

It has to be noted that it is much more difficult to achieve good modelling statistics at the daily time step than at monthly or annual steps. This is because at the monthly time scale, a lot of smoothing is taking place, given the time-scale of the most dominant processes in soil water and heat regimes at the monthly step there is a significant degree of smoothing involved, which is easier for the model to capture. In other words, it is much easier to predict a mean value (or similar) than to predict the fluctuations.

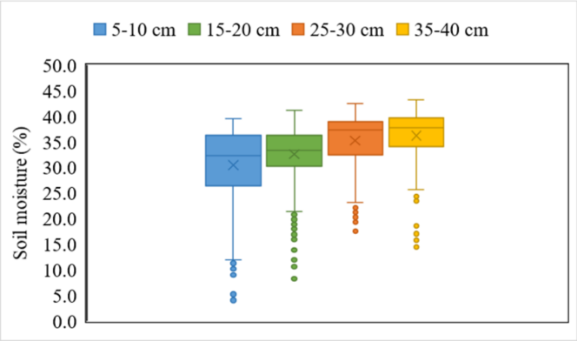
## 3. Results

### 3.1 Effect of tillage on soil and plant characteristics

On the base of the five-year long period of the field experiment we can conclude that yearly Ts course is mainly governed by air temperature at all of the investigated soil depth (*5-10, 15-20, 25-30, 40-45 cm).* At the depth of 5-10 cm and 15-20 cm no significant differences occurred between Ts of different treatments for the whole investigated period (p=0.0596 and p=0.9898, respectively). Nevertheless in the year of 2015 Ts at the 5-10 cm and the 15-20 cm soil depth in the SC treatment was significantly lower compared to P (p= 0.0033 and p=0.0074, respectively) and NT (p=0.0138 and p=0.0034, respectively). At the depth of 25-30 cm, Ts of SC treatment was significantly lower (p=0.0076) compared to NT, but there was no differences in Ts between SC and P (p=0.7409) and P and NT (0.1450).

The yearly course of SWC is governed by precipitation and air temperature, however arid periods had a stronger drying effect on soil SWC in P and SC treatments. SWC of NT at the 5-10, 15-20 and 35-40 cm depth was significantly higher compared to P and SC treatments (p<0.0001). The tillage application had a strong effect on SWC even at the depth of 25-30 cm where SWC of NT was also significantly higher compared to SWC of P (p<0.0001) and SWC of SC (p<0.0334). SWC also significantly differed in the different depth in each treatments (p<0,0001). In the P and NT treatment SWC increased with soil depth, but in the SC treatment SWC increased till the depth of 35-30 cm than became lower at the depth of 40-45 cm. Variability of SWC in different treatments are shown in Figure 2. All of the treatments had higher SWC during periods without vegetation cover than in the periods with vegetation cover in the 5-10 cm depth. More detailed results of the period of 2015, and 2019-2020 can be found in Tóth et al, 2018a and Dencső et al., 2021.

a)



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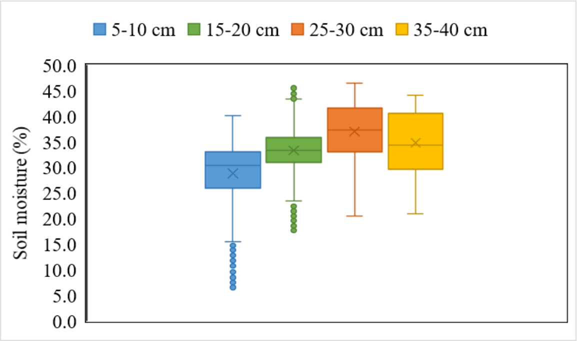


*c)*

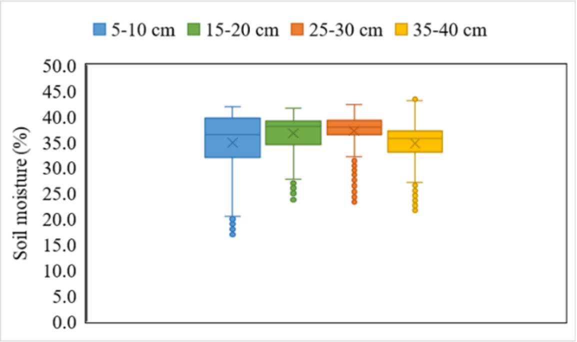


Figure 2. Median and variability of soil water content at the depth of 5-10, 15-20, 25-30 and 35-40 cm in the a) ploughing, b) shallow cultivation and c) no-tillage treatments

Soil chemical characteristics such as total humus content and total nitrogen (N) content can be one of the main chemical drivers of $CO_2$ and $N_2O$ emission. Although these parameters have their own temporal variability, it can be seen in Figure 3 that significant differences occured between the treatments. Both humus and N content values are the highest in NT treatment, while lowest values were determined in P treatment.

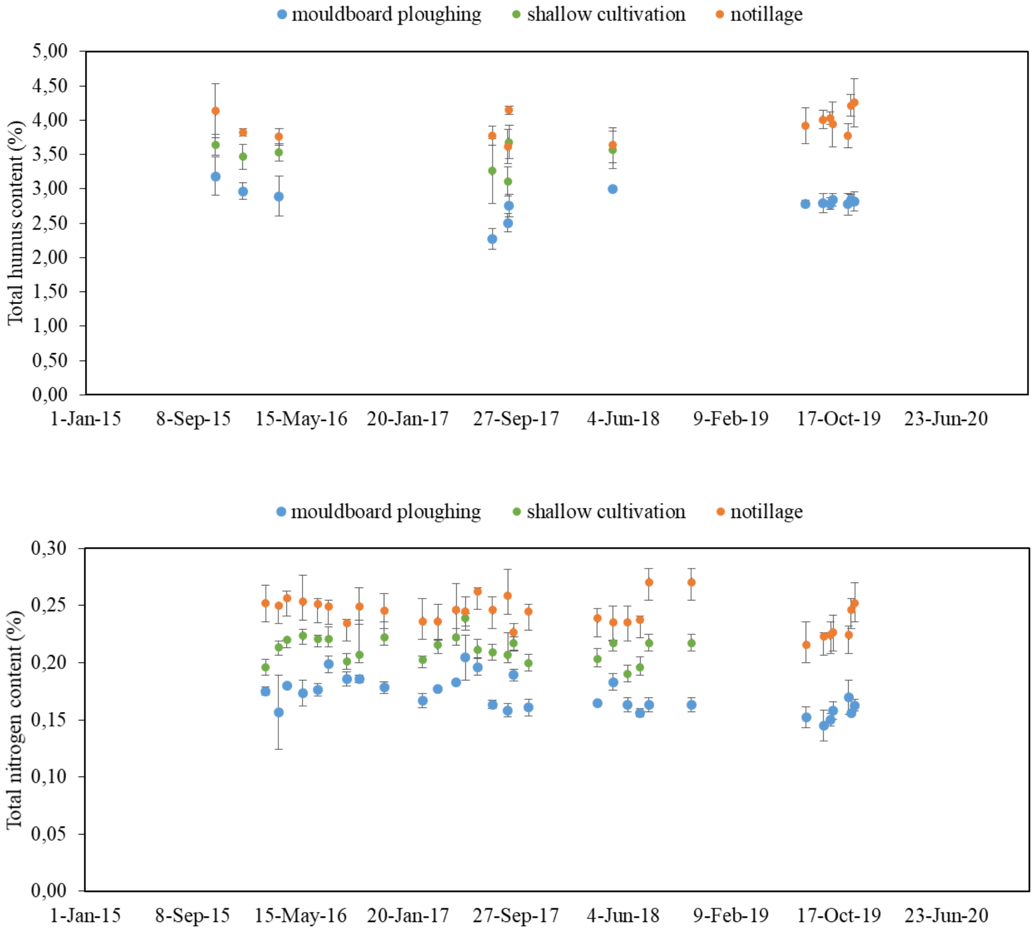
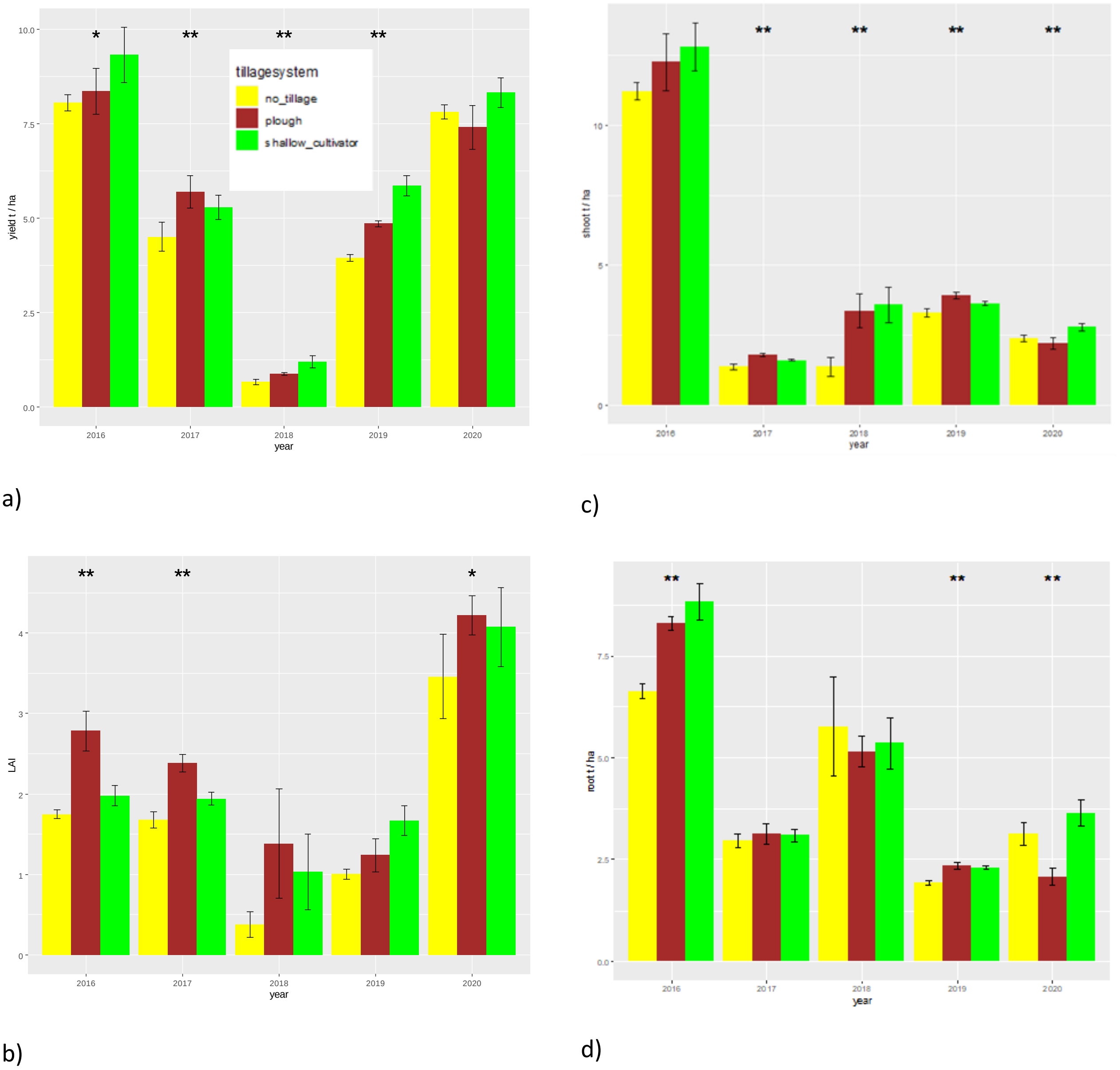


Figure 3. Changes in humus and total nitrogen content in the different treatments between 2015-2019.

Different plant characteristisc such as yield, root biomass, shoot biomass and leaf area index (LAI) was also measured during the project period and results can be seen in Figure 4. These parameters can be used also as input parameters during modeling works. Although soil $CO_2$ emission was significantly higher in NT than in P treatment, LAI which shows well the plant development was always the smallest in NT treatment. Neverthesless, LAI values were significant higher in 2016, 2017 and 2020 in P compared to NT treatments. Also root biomass which is responsible for root respiration is smaller in 3 of the 5 years in NT treatments than in P or SC treatments. The highest yields could be observed in SC treatment in all the years except in 2017. Although it is hard to find connection between $CO_2$ emissions and the measured plant characteristisc even so they gave valuable infromation about the effects of different tillage. Yield, shoot-and root biomass values were determined on the base of one measurement, however more frequent sampling would give more comprehensive result



a)

c)

b)

d)

Figure 4. Plant characteristics such as yield (a), LAI (b), shoot biomass (c) and root biomass (d) in the different treatments between 2016 and 2020. * represents significant differennces between treatments.

## 3.2 Effect of environmental drivers on soil GHG emissions

Soil $CO_2$ emission has a yearly course similar to air and soil temperature trends in all tillage treatments (Figure 5.). Since SWC highly depended on the presence or lack of vegetation cover, we evaluated the effect of SWC on GHG emissions in the vegetation period and in the after harvest period separately. Detailed results about the environmental governing factors of GHG emissions in field experiment can be seen in Dencső et al., 2021.

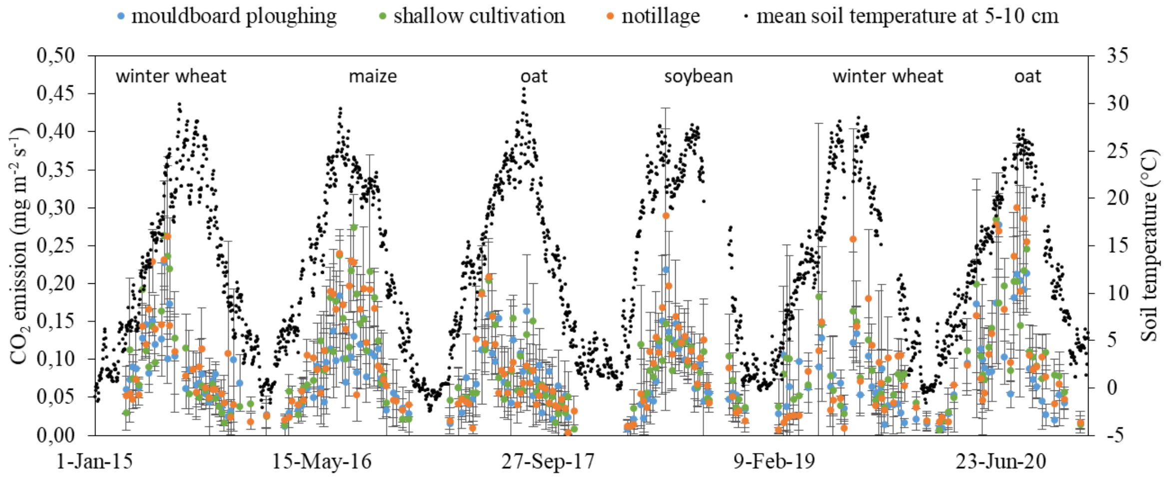
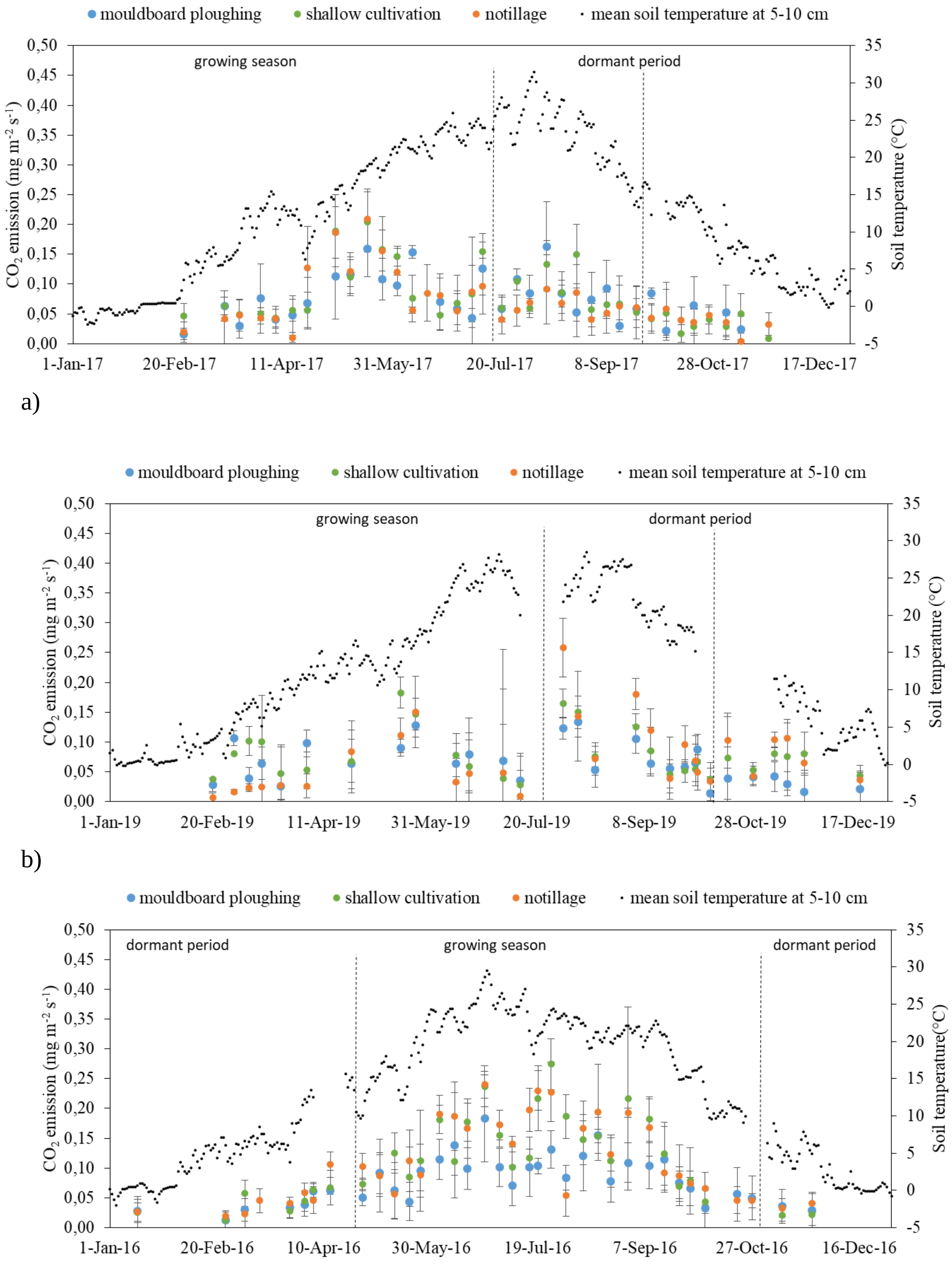


Figure 5. Yearly course of soil $CO_2$ emissions and soil temperature at the depth of 5-10 cm in the P, SC and NT treatments.

## 3.2 Long-term effect of tillage on soil GHG emissions

Average soil $CO_2$ emissions during the whole experiment period (2015-2020) differed significantly ($p=0.002$) in the three treatments. The smallest yearly average emission occurred in the P treatments in all years with significant difference compared to NT ($p=0.0182$) and SC ($p=0.002$) treatments. However emissions in NT and SC had not got such an obvious trend and the largest yearly emissions occurred in half of the years' in NT and in the other half of the years' in SC treatments with no significant differences between them ($p=0.5395$). Evaluating emissions data yearly, we can conclude that no significant differences occurred between treatments in 2015, 2017 and 2019 ($p=0.5398$, $p=0.5134$ and $p=0.1421$, respectively). In 2016 and 2018 and 2020 the average yearly emission was significantly higher in SC than in P treatments ($p=0.0056$, $p=0.0160$ and $p=0.0343$, respectively). Average yearly emission in P and NT treatments differed significantly only in the year of 2016 ($p=0.0265$), when emission was higher in NT treatments. After data evaluation we observed different trend in $CO_2$ emissions in the years (2015, 2017, 2019, 2020) when winter crop was cultivated compared to the years (2016, 2018) when summer crop was sown. Soil $CO_2$ emission and Ts of topsoil increased parallel in years with winter crop till the middle-end of the vegetation period than a decreasing trend in soil $CO_2$ emission could be observed till harvest while Ts was still increased (Figure 6a,b). After harvest a secondary peak occurred in soil $CO_2$ emission than started to decrease again after autumn came. In summer crop years this secondary peak didn't occure and soil $CO_2$ emission followed the trend of Ts (Figure6c).

a)



a)

b)

c)

Figure 6. Yearly course of CO2 emission in the year of 2017 (a), 2019 (b) and 2016 (c)

Soil N$_2$O emission didn't have a well-specified yearly course (Figure7), however occasional peaks could be noticed and standard deviation of the emission was extremely high. This is consistent with the large spatial and temporal heterogeneity of the $N_2O$ emission. Bigger peaks were observed in the year of 2019 and at the beginning of 2020, however the rest part of 2020 no $N_2O$ peaks occurred. During the whole investigated period $N_2O$ emissions differed significantly between treatments ($p=0.002$) with highest values in NT. Highest differences in N2O emissions occurred in the year of 2019, nevertheless in 2020 no differences could be determined between the three treatment ($p=0.2549$).

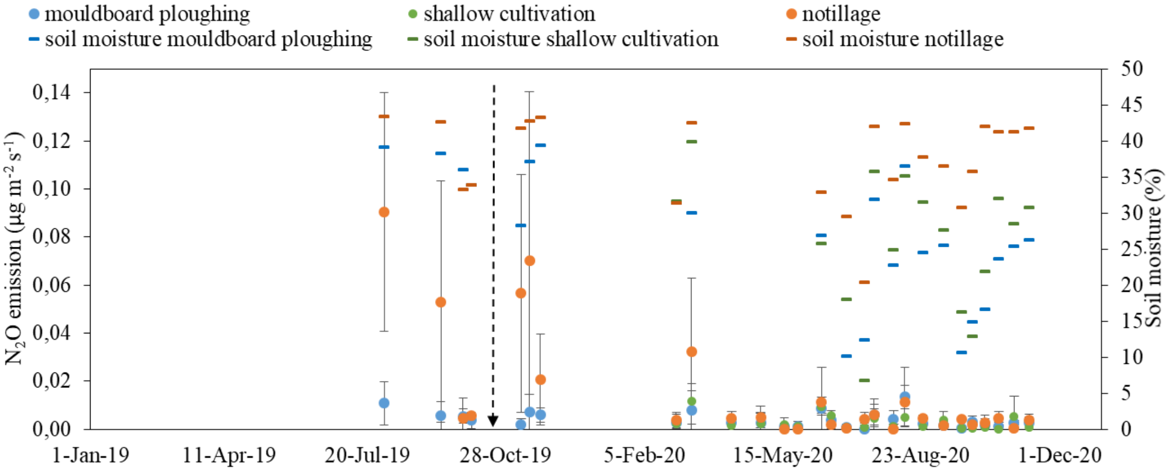


Figure 7. Yearly course of N2O emission in 2019 and 2020

3.3 Short-term effect of tillage on soil GHG emissions

Although we could find significant differences between soil $CO_2$ emissions in different treatment investigating the whole experiment period, these differences were not always significant in a certain year. Therefore we made a campaign $CO_2$ emission measurement right after tillage operation. During this campaign a pretreatment control measurement was made just before the plowing event then sampling was performed hourly in the first 7 h, then at 12, 18, and 24 h and 2, 3, 4, 5, and 6 days after the plowing (Figure 8)

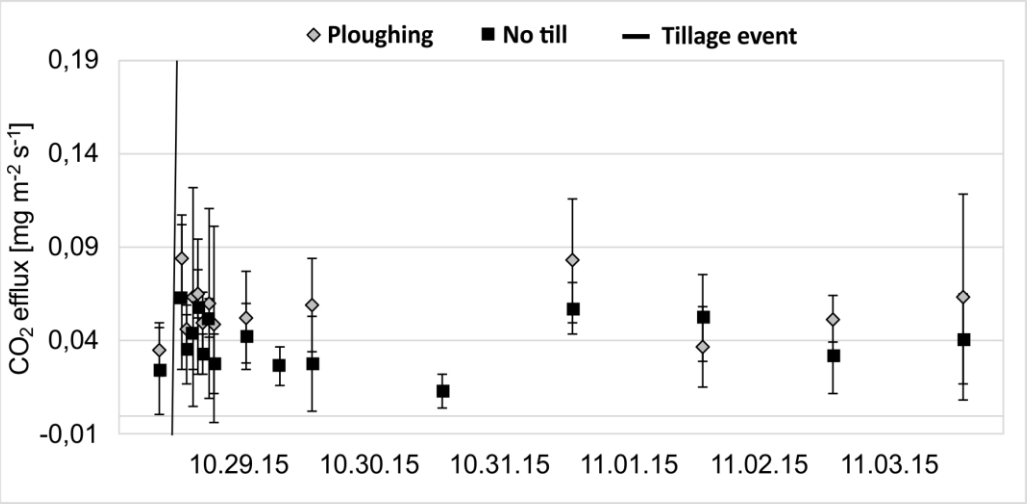


Figure 8. Soil $CO_2$ emissions right after tillage application in 2015 in ploughing and no-till treatments.

Following the plowing event, an increase in microbial activity can be expected, as better aeration is occurring during the process. The disturbance of soil also supports the sudden release of $CO_2$ produced below the surface. According to our measurements after plowing, the $CO_2$ emissions trend observed in the vegetation period changed, as plowing resulted in higher $CO_2$ emissions in most cases. Better aeration of the soil by plowing can cause enhanced microbial activities, such as dormant aerobe or facultative microorganisms in the soil that can use oxygen to oxidize substrates and grow. The plowing event resulted in significant differences in soil $CO_2$ emissions between treatments during the 150 h the measurements were taken ($P < 0.01$). During the first four days following soil tillage we found that soil $CO_2$ emissions in the P treatment were 52.6% higher compared to NT treatment, and 72.8% higher than the value measured just before tillage. Our findings support that the treatment type has a major influence on soil $CO_2$ emissions for at least a week after the soil disturbance; however, this effect diminishes over a longer time period. Tillage application also caused a substantial difference between P and NT SWC at the upper soil layers (26.30±0.23% and 39.99 ± 0.15%, respectively). The drying of the soil in the P treatment from the ~33.5% VWC before plowing was likely caused by the incorporation of plant residues into the soil, leading a bare soil surface with enhanced evaporation and the loosening of soil structure. These SWC changes alone can represent the major differences in the present data, which were directly related to soil tillage types. Temperature, on the other hand, showed relatively smaller differences between treatments, as P had 9.38°C±1.27°C) while NT had 7.86°C ±1.87°C) in the upper soil layer over the week of the study. More detailed findings can be found in Tóth et al., 2018a.

### 3.4 Effect of fertilization on soil GHG emission

This topic was not the main objective of the project, since only soil column experiments were planned with different fertilizer doses. The results of these experiments can be found in Dencső et al, 2021.

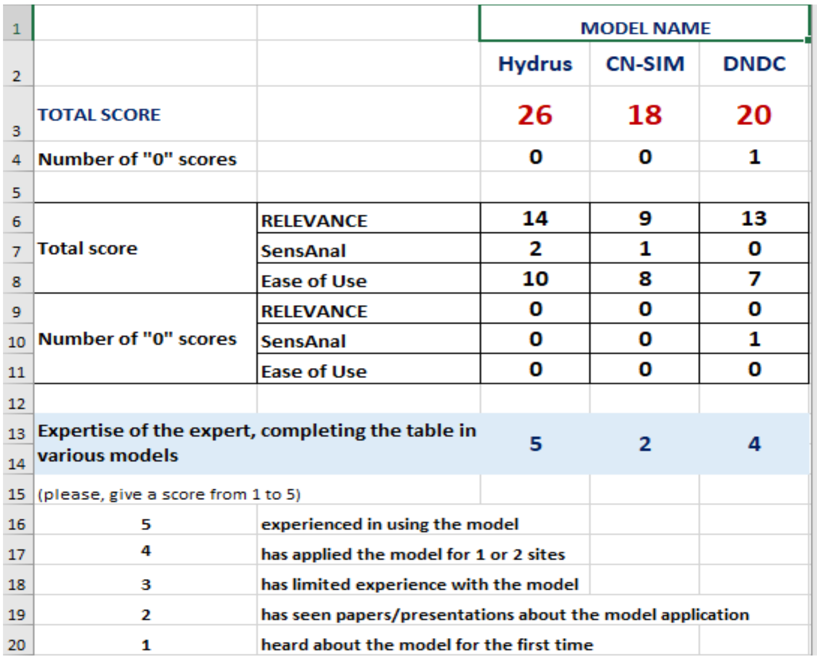
### 3.5 Modeling

Based on the benchmark criteria, we performed a preliminary model evaluation to select an appropriate mathematical model for simulating the water, heat and $CO_2$ regimes in tilled soils. Specific attention was given to the model's sensitivity to tillage-induced changes in soil structure and soil hydraulic properties, so the differences between the studied treatments could be described. We evaluated three different models, pre-selected based on relevant review articles (Maharjan et al., 2018) and other relevant literature review. The three models were the DNDC (https://www.dndc.sr.unh.edu/; Balashov et al., 2004), the CN-SIM model (Petersen et al., 2005; Chatskikh et al., 2008) and the HYDRUS-1D (https://www.pc-progress.com/en/Default.aspx?hydrus-1d; Simunek et al., 2012) model. The list of criteria that was deemed most important is as follows:

Q1.1. How well does the model's output relate to the management task?
Q1.2. How well does the model's spatio-temporal resolution match the requirements of the task?
Q1.3. How well has the model been tested?
Q1.4. How complicated is the model in relation to the task?
Q1.5. How is the balance between the model's input data and data availability?
Q1.8. How is the peer acceptance for the model with scientific theory?
Q3.5. How is the model's flexibility for adaptation and improvements

We gave scores from 1 to 5 for these questions which were automatically summed up for each of the evaluated model in a separate sheet (Table 3).

Table 3: Final outcome of the model's evaluation procedure, following the criteria of Saloranta et al. (2003)



| | | | | | |
|---|---|---|---|---|---|
| 1 | | | MODEL NAME | | |
| 2 | | | Hydrus | CN-SIM | DNDC |
| 3 | TOTAL SCORE | | 26 | 18 | 20 |
| 4 | Number of "0" scores | | 0 | 0 | 1 |
| 5 | | | | | |
| 6 | Total score | RELEVANCE | 14 | 9 | 13 |
| 7 | | SensAnal | 2 | 1 | 0 |
| 8 | | Ease of Use | 10 | 8 | 7 |
| 9 | Number of "0" scores | RELEVANCE | 0 | 0 | 0 |
| 10 | | SensAnal | 0 | 0 | 1 |
| 11 | | Ease of Use | 0 | 0 | 0 |
| 12 | | | | | |
| 13 | Expertise of the expert, completing the table in various models | | 5 | 2 | 4 |
| 14 | | | | | |
| 15 | (please, give a score from 1 to 5) | | | | |
| 16 | 5 | experienced in using the model | | | |
| 17 | 4 | has applied the model for 1 or 2 sites | | | |
| 18 | 3 | has limited experience with the model | | | |
| 19 | 2 | has seen papers/presentations about the model application | | | |
| 20 | 1 | heard about the model for the first time | | | |

Table 4. Hydrus-1D model set up for the three different projects

| | **Project 1** | **Project 2** | **Project 3** |
|---|---|---|---|
| | **Direct drilling** | **Ploughing** | **Cultivator** |
| **Main processes set up** | Water flow, Heat transport, Root water uptake, Root growth, ($CO_2$ transport) | | |
| **Simulation period** | 01.01.2015 – 31.12.2015 | | |
| **Water transport** | | | |
| Upper boundary conditions | Atmospheric BC with surface run off (derived from daily meteorological data) | | |
| Lower boundary conditions | Free drainage | | |
| Initial condition | Soil water content as a function of depth on the starting day (01.01.2015) | | |
| **Heat transport** | | | |
| Upper boundary conditions | Temperature boundary conditions | | |
| Lower boundary conditions | Zero gradient | | |
| **Carbon Dioxide Transport** | | | |
| Upper boundary conditions | Concentration boundary condition (0.00033 $cm^3$ $cm^{-3}$) | | |
| Lower boundary conditions | Concentration flux boundary condition (0.0004 $cm^3$ $cm^{-3}$) | | |
| Specifications | Gas phase is not stagnant | | |
| **Time variable boundary conditions** | | | |
| Meteorological parameters<br>Meteorological conditions | Data from meteorological stations (precipitation, min and max air temperature, solar radiation, relative humidity, wind speed) | | |
| **Soil profile summary** | | | |
| Number of soil layers | 3 | 3+1 (plough pan) | 3 |
| Soil discretization | 0-10, 10-30, 30-50 cm | 0-10, 10-30, 30-35, 35-50 cm | 0-10, 10-30, 30-50 cm |

From the evaluation, the Hydrus-1D model emerged as the most potent one to use to meet the Project's objectives for several reasons, e.g. i) precise, physically-based description of the water and heat regimes within the soil profile; ii) high sensitivity to tillage-induced changes in soil hydraulic properties; iii) proven applicability to the study area in sense of soil hydrology. Therefore, data, collected within the Project were further evaluated, using the Hydrus-1D model. Accordingly, we applied the pre-selected Hydrus-1D model to simulate the soil heat and water content dynamics for the growing season of 2015 using the Hydrus1D model (Simunek et al., 2012) and to evaluate the model's capability to simulate the $CO_2$ fluxes. Three model projects have been created, on for each tillage treatment studied. Specification of the model set up are given in Table 4. All the model parameters that we had measured data about were set up according to the measurements. The most important model parameters are given in Table 5. As we did not success in fitting the CO2 transport parameters, those are not given in the table. The initial values, used for calibration were set according to Buchner et. al (2008).Further, the model was calibrated by fine-tuning the model parameters to minimize the difference between the simulated and measured values of soil water content (first step), soil temperature (second step) and $CO_2$ flux. An overview of the reference data, used for model calibration is given in Table 6.

Table 5. Hydrus-1D model parameters, set up for the different tillage treatments

| | **Project 1** | **Project 2** | **Project 3** |
|---|---|---|---|
| | **Direct drilling** | **Ploughing** | **Cultivator** |
| **Water transport parameters** (*soil layers 1/2/3*) | | | |
| Model for soil hydraulic functions | Single porosity model: Van Genuchten – Mualem | | |
| Residual water content (-) | 0.001/0.030/0.026 | 0.045/0.080/0.001 | /0.851 |
| Saturated water content (-) | 0.422/0.420/0.454 | 0.350/0.350/0.453 | /0.404 |
| Alpha (1/cm) | 0.015/0.023/0.030 | 0.022/0.009/0.025 | /0.0001 |
| n (-) | 1.150/1.118/1.150 | 1.120/1.167/1.141 | /1.296 |
| $K_s$ (cm/day) | 80.9/46.0/12.9 | 148.5/2000/10.4 | /33.6 |
| I (-) | -0.84/-0.01/-0.02 | -0.545/-3/-0.592 | /-2.583 |
| **Heat transport parameters** (*soil layers 1/2/3*) | | | |
| Model for thermal conductivity | Campbell | | |
| Volume fraction - soil phase (-) | 0.578/0.580/0.546 | 0.578/0.580/0.546 | 0.578/0.580/0.547 |
| Volume fraction – organic matter (-) | 0.03/0.02/0.01 | 0.03/0.02/0.01 | 0.03/0.02/0.01 |
| Longitudinal thermal dispersivity (cm) | 0.2/0.5/0.5 | 0.2/0.5/0.5 | 0.2/0.5/0.5 |
| Volumetric heat capacities (J $cm^{-3}$ $K^{-1}$) | Default values of the Cambell function are used as built in the Hydrus model | | |
| **Crop parameters** | | | |
| Crop type | Winter wheat | | |
| Sowing date | 08/10/2014 | | |
| Harvesting date | 08/09/2015 | | |
| Root water uptake model | Feddes (parameters taken from the Hydrus database for wheat) | | |
| Solute stress model | No solute stress | | |
| **Crop development (crop height (cm); albedo (-); LAI (-); rooting depth (cm))** | | | |
| Days: 100 | 5/0.23/0.1/5 | 5/0.23/0.1/5 | 5/0.23/0.1/5 |
| 128 | 10/0.20/0.5/10 | 10/0.20/0.5/10 | 10/0.20/0.5/10 |
| 133 | 15/0.18/1.0/15 | 15/0.18/1.0/15 | 15/0.18/1.0/15 |
| 150 | 25/0.15/1.5/25 | 25/0.15/1.5/25 | 25/0.15/1.5/25 |
| 180 | 45/0.15/2.2/45 | 45/0.15/2.2/30 | 45/0.15/2.2/45 |
| 210 | 60/0.15/2.4/50 | 60/0.15/2.4/35 | 60/0.15/2.4/50 |
| 250 | 73/0.15/2.0/50 | 73/0.15/2.0/35 | 73/0.15/2.0/50 |
| 255 | 0/0.23/0.20/0.1 | 0/0.23/0.20/0.1 | 0/0.23/0.20/0.1 |

Table 6. Reference data used for model calibration

| **Year: 2015** | **Project 1** | **Project 2** | **Project 3** |
|---|---|---|---|
| | **Direct drilling** | **Ploughing** | **Cultivator** |
| **Water transport – measured soil water content (SWC) dynamics** | | | |
| Depth of the measurement | 5-10, 15-20, 30-35, 40-45 cm | | |
| Number of available data | | | |
| 5-10 cm | 268 | 216 | 281 |
| 15-20 cm | 300 | 281 | 293 |
| 30-35 cm | 310 | 291 | 293 |
| 40-45 cm | 310 | 291 | 140 |
| Mean/min/max value (-) | | | |
| 5-10 cm | 0.24/0.14/0.41 | 0.21/0.13/0.29 | 0.22/0.11/0.35 |
| 15-20 cm | 0.26/0.12/0.40 | 0.22/0.16/0.31 | 0.21/0.11/0.31 |
| 30-35 cm | 0.27/0.14/0.41 | 0.24/0.17/0.31 | 0.19/0.10/0.29 |
| 40-45 cm | 0.25/0.14/0.32 | 0.22/0.18/0.32 | 0.18/0.15/0.29 |
| **Heat transport – measured soil temperature (ST) dynamics** | | | |
| Depth of the measurement | 5-10, 15-20, 30-35, 40-45 cm | | |
| Number of available data | | | |
| 5-10 cm | 349 | 291 | 291 |
| 15-20 cm | 365 | 290 | 293 |
| 30-35 cm | 365 | 291 | 293 |
| 40-45 cm | 365 | 290 | 140 |
| Mean/min/max value (-) | | | |
| 5-10 cm | 12.2/-0.9/29.0 | 13.0/-2.2/31.4 | 10.4/-1.3/29.9 |
| 15-20 cm | 12.5/0.01/27.0 | 12.8/-0.4/28.5 | 10.4/1.1/26.4 |
| 30-35 cm | 12.5/0.6/25.5 | 13.0/1.3/27.1 | 10.5/0.2/23.7 |
| 40-45 cm | 12.3/1.8/24.7 | 12.9/1.7/24.8 | 13.2/5.1/22.5 |
| **CO2 dynamics – measured flux at the soil surface** | | | |
| Number of available data | 32 | 31 | 31 |
| Mean/min/max value (-) | 0.087/0.025/0.228 | 0.094/0.017/0.251 | 0.099/0.021/0.262 |

Results of modelling soil water and heat dynamics are visualized in Figure 9 and 10. The statistical evaluation of the goodness-of-fitting is given in Table 7. For the NT and P treatments (apart of the topsoil in the P treatment) the Hydrus model could simulate the water content and heat regimes of the soil for different tillage systems rather well: according to the N-S and PBIAS values, all the calibration results of the soil temperature fall into the “very good” range, and the soil water content simulations fall in “good” or “very good” category (Table 2). Considering, that the values given in Table 2 are related to monthly time step while we presented simulations on daily time step, our simulation results are rather precise. We assume, that the large clods and the specific soil structure, created by the ploughing treatment in the topsoil were the reason of poor calibration in the upper 10 layer of the P treatment. Concerning the cultivator treatment, similarly good results were obtained for the Ts calibration as in the other two treatments, but we faced challenges when simulating the soil water regime. This was the only treatment where it was necessary to separate the period before and after the tillage operation (which took place in October 2015). There was not enough sufficient data for modelling the late autumn period, therefore we were focusing on the first 200 days, for which we had sufficient data from the soil moisture probes. In sense of water balance (total differences, indicated by PBIAS), good or very good results were obtained, but the model could hardly capture the pattern of the soil water content dynamics during the vegetation period. We believe that the model failed capturing the root water uptake precisely in the SC treatment, and this lead to less satisfactory calibration results.

Precise simulation of the soil water and heat regimes are essential for estimating $CO_2$ regime in the soil. As we achieved good calibration results for the NT and P treatments, we have set up several Hydrus-1D projects aiming to simulate the soil $CO_2$ regime in these tillage systems, but the modelling results gave very poor correlation with the measured data. Moreover, when adding the $CO_2$ transport to the main processes simulated, our previously obtained good estimates for soil temperature and water content failed and gave unrealistic results; the model failed following even the initial conditions, which were pre-defined. We also tried to model separately the vegetation period and the non-covered period to turn off root respiration but it didn’t bring result. We could not find many cases, where the Hydrus-1D model was used for such studies, so most probably the model worked well for the cases for which the $CO_2$ transport module was developed for, but seemed not to be suitable for our experiment. On the other hand, this study is based on an unusual amount of soil respiration data; and the more data we have, the more wide range on conditions the model has to capture and the more difficult to fit the simulated fluxes to the measured values. Learning from this lesson, we are planning to discuss our experience with the Hydrus model developer team and also to look up other alternatives to estimate the $CO_2$ flux from the soil in our future work.

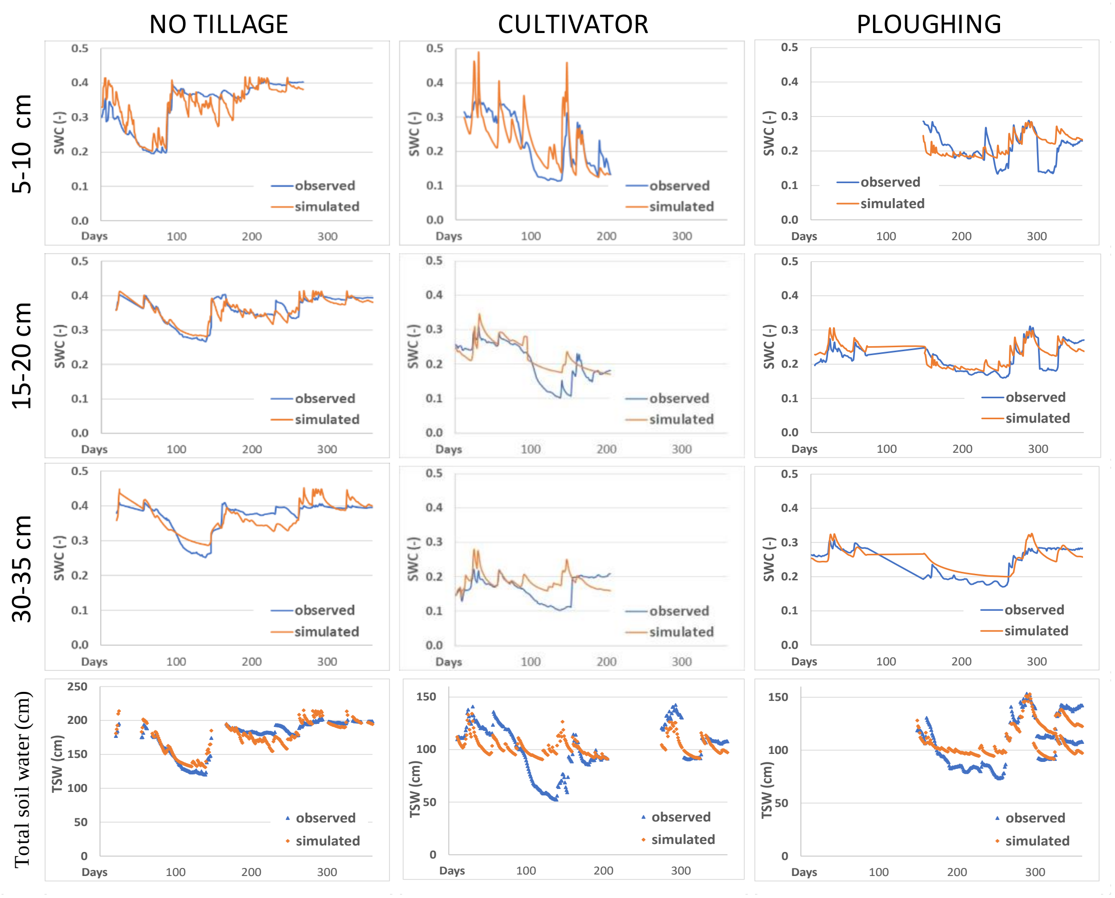


Figure 9. Observed and simulated soil water content (-) values and total soil water in the 0-50 cm layer (cm) for the different soil tillage systems

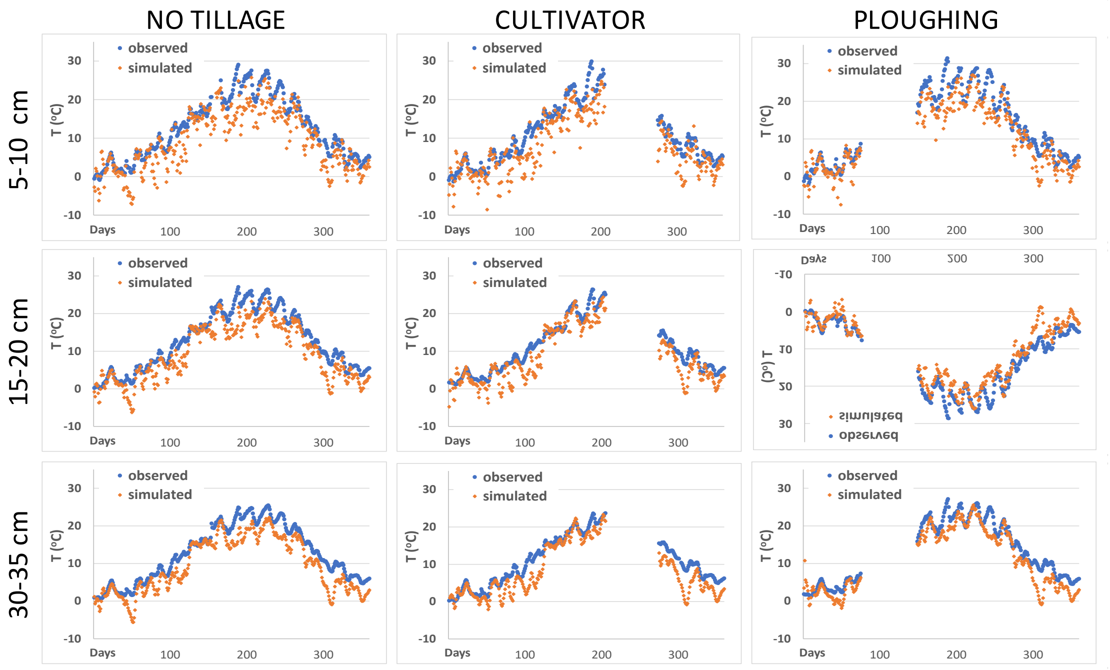


Figure 9. Observed and simulated soil temperature (ºC) for the different soil tillage systems

Table 7. Statistical evaluation of the model performance

| Year | Soil layer (cm) | Characteristics | No tillage | | | Cultivator | | | Ploughing | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $R^2$ | N-S | PBIAS | $R^2$ | N-S | PBIAS | $R^2$ | N-S | PBIAS |
| 2015 | 5-10 | Soil water content | 0.76 | 0.76 | 0 | 0.52 | 0.47 | 1 | 0.12 | -0.01 | 3 |
| | | Soil temperature | 0.90 | 0.73 | | 0.83 | 0.65 | | 0.88 | 0.79 | |
| | 15-20 | Soil water content | 0.83 | 0.83 | 0 | 0.67 | 0.53 | 1 | 0.63 | 0.54 | 4 |
| | | Soil temperature | 0.90 | 0.73 | | 0.88 | 0.73 | | 0.91 | 0.84 | |
| | 30-35 | Soil water content | 0.65 | 0.63 | 0 | 0.03 | -0.60 | 12 | 0.71 | 0.69 | 2 |
| | | Soil temperature | 0.92 | 0.93 | | 0.86 | 0.91 | | 0.89 | 0.94 | |
| | | Total Soil Water | 0.82 | 0.82 | 0 | 0.28 | 0.24 | 1 | 0.83 | 0.74 | 3 |

Note: the dark green, green, yellow and orange colors indicate very good, good, satisfactory and unsatisfactory model performance, respectively

## 4. Conclusions

We measured soil $CO_2$, $N_2O$ emissions and continuously monitored SWC and Ts during the period of 2015-2020. After evaluation of the dataset, we concluded that soil tillage treatments have significant effects on the yearly course of these parameters. NT treatment have significantly higher SWC than P, beacause of the lack of intensive soil aeration caused by tillage application. Although NT had also higher $CO_2$ emission it doesn't mean that this type of land management is a carbon reducing intervention since soil of this treatment had higher humus content already at the beginning of our investigation (13 years after the experimental set up). Nevertheless to give recommendation for the best management practices, plant characteristics, especially crop yield must be also taken into consideration. Crop yield is a very important parameters not only for farmers because of the profit but also globally to ensure the increasing food demand. In all the studied years except one (2020) cop yield was the lowest in the NT treatment which questions its applicability under our climatic and environmental conditions. However, SC treatment seems a good solution from the point of view of soil water regime and crop yield as well. Yield in SC treatment was the highest in all years except in 2017, even it was also higher than yield in P treatment. Although SWC was lower in SC than in NT treatment, this difference was not significant in most of the years.

## 5. The Project's achievements in the light of the expected deliverables

According to the research plan of the project, the main objectives (O) and expected results (ER) were the following:

(O) To design and carry out laboratory measurements of biotic and abiotic factors, determining soil properties, soil carbon balance and soil $CO_2$ and $N_2O$ emission. *Results are published in Dencső et al., 2021.*

(O) To carry out plot scale *in-situ* campaign and regular measurements of GHG emissions and continuous monitoring of ancillary factors in three selected tillage treatments (shallow cultivation, ploughing, no-till). *Results of different years are published in Tóth et al., 2018a and Dencső et al, 2021. A comprehensive summary of 5 years of measurement data is under review in Soil&Tillage Research. Results from 2015-2020 are also presented in this report.*

(O) To evaluate the multi-scale (laboratory and field) database for detecting the relationship between soil physical, biological properties and GHG emission. *Results of presented in this report.*

O) To draw grounded conclusions on the seasonal effects of tillage systems on soil properties, soil respiration and carbon stocks. *Detailed information about tillage effect in the vegetation period and in periods with no vegetation cover is presented in Dencső et al., 2021.*

(O) To give recommendations on soil and water conserving soil management practices that facilitate carbon sequestration. *Recommendations are given in this report in the conclusion part.*

(O) To evaluate treatments of different tillage practices with a common fertilizer application regarding GHG emissions to optimize joint emissions. *Detailed information is given in Dencső et al., 2021*

(O) To overview plot scale models for $N_2O$ and $CO_2$ emission and to evaluate them on the base of the Benchmark criteria in order to select a model, best meeting the project's objectives. *Three plot scale models were evaluated, results are presented in this report.*

(O) To parameterize and calibrate the selected models at laboratory and plot scales, using available data (for carbon regime only) and data obtained in the frame of the present project (for both, soil C and N regimes). *We used our measured data for model parametrization and calibration.*

(O) To evaluate the ability of the applied modelling approach to simulate the soil heat-, water- and $CO_2$ and $N_2O$ regimes at the studied scales for different soil management systems. *Soil heat-and water regime can be satisfactory simulated by Hydrus model, however we didn't succeed to fit* $CO_2$ *transport parameters, the detailed results are presented in this report.*

(O) To test the sensitivity of the chosen model with measured data and confirm its suitability to show differences caused by different treatments. *With respect to the water regime, the Hydrus model showed the highest sensitivity to the soil hydraulic properties. As mechanical disturbance, like soil tillage, modifies primarily the soil structure and consequently soil hydraulic properties, the model was capable to describe the differences between the different soil tillage systems during the study period. Thermal parameters, listed in the report in Table 5 are those that had the biggest influence on model output.*

(ER) The project results would create a knowledge-based background for modelling $CO_2$ and $N_2O$ emission from Hungarian arable lands, including multi-scale calibrated parameter sets for the models. *The multi-scale database, collected within the frames of the project, involving pot-, and plot-level measurements and the lessons learnt from modelling the water, heat and $CO_2$ regime highlighted the opportunities and constrains of modelling the GHG emission from arable land*

(ER) The project outcomes would support the improvement of ecosystem scale carbon and nitrogen cycle modelling and evaluation of ecosystem services in different management systems. *The results of the Project highly contributed to the better understanding of the main drivers and formulation of GHG emission and provided improved prediction of the abiotic drivers of soil CO2 and N2O emission. The tools developed (calibrated model parameters and statistical relationships) and the knowledge gained can highly contribute, in the future, to the assessment of ecosystem services in agricultural and natural ecosystems.*

(ER) The project would produce publications in international peer reviewed journals, research topic for an MSc or a BSc student. *A PhD student was involved into the project in 2015. He is in the finish in the PhD process*.

## 6. Publication activity

I went to maternity leave 9 month later than the project started so the first project year lasted between 2015 and 2018. During this period of the project the main focus was on database construction, on the set up soil water content-and temperature monitoring at the experimental site and do the campaign measurements after tillage application. Also regular $CO_2$ emission measurements started in the three chosen tillage treatments. Data evaluation stopped for a time because of my leaving so half part of the publications were mostly including conference papers and presentations, however peer-reviewed articles were mostly studies with methodical similarities on soil water and respiration under different land management systems. Such publications were presented by Gelybó et al., 2015 (conference proceeding), by Dencső et al., 2017a and by Horel et al., 2017 and 2018b (peer-reviewed papers). Two conference presentation (Dencső et al, 2016ab and Dencső et al, 2017b) directly from the first field experiment results were held in the year of 2016 and 2017 by my PhD student who was involved into the project in the first year and also two abstract were presented in the international EGU conference by Gelybó et al., 2016., Dencső et al., 2017c. The first outcomes and the results about the short-term effects on soil respiration was published in a book chapter by Tóth et al., 2018a.

In the second year of the project we showed our results in several conference abstract and poster. We presented the differences and similarities of two $CO_2$ emission measurement methods in Dencső et al.,2018ab the effect of different tillage methods on soil respiration in Gelybó et al., 2018a, Dencső et al., 2018c., the main driving factors in Tóth et al, 2018b, Pokovai et al, 2018 and Horel et al, 2018a. In this year also two peer-reviewed paper was presented. A review article was published in Agrokémia és Talajtan (Q3) in English where the potential impacts of climate change on soil properties were analyzed in greater detail (Gelybó et al., 2018b) A methodology related research article was published in Sustainability (impact factor: 2.592, Q2) in 2018, where soil $CO_2$ and $N_2O$ emission drivers were investigated under different soil management systems and amendments (Horel et al., 2018b). In the year of 2019 we continued to present our result in national and international conferences. Experiences with our new portable gas analyser was presented in Dencső et al, 2019. The first results of the laboratory column experiment was presented by Tóth et al, 2019 in an oral presentation. A short summary about five-year long results of the tillage experiment was shown by Gelybó et al, 2019. Results of $CO_2$ and $N_2O$

emission measurements on a different field was presented by Horel et al 2019a. Two peer-reviewed paper was also published in this year. The first results from successful calibration and validation of the HYDRUS 1D model was accomplished, where soil water changes were simulated while varying biochar amounts. These findings were published in the journal of Agronomy (impact factor 2.259, Q1) (Horel et al., 2019b). Some methodology-related results were published in Baklanov et al 2019 in Agrokémia és Talajtan (Q3) about methods for nitrogen cycling measurements. In 2020 travel was not allowed because of the Covid-19 Pandemia, so we had only two international conference abstracts. We presented the preliminary results by Tóth et al., 2020a about the heterogeneity analyses of the field experiment, where in the no till and in the ploughing treatments150 sampling points were determined in a quadrat, where soil temperature, soil $CO_2$ emission, soil organic carbon content and soil water content were determined. Also the first results about the driving factors of $N_2O$ emission was presented in an abstract by Dencső et al, 2020. Four peer-reviewed papers was also published in this period of the project. A comprehensive study was published by Bakacsi et al, 2020 in STUDIES IN AGRICULTURAL ECONOMICS about countrywide soil nutrient emission models where data collected during the project was also presented. The experiences and possibilities about the newly-bought portable gas analyzer was presented by Tóth et el, 2020b in Agrokémia és Talajtan (Q3). A methodology-related paper was published by Pokovai et al., 2020 about plant measurements in Applied Science (Q1, IF:2,474). The main findings about the laboratory soil column experiments and about the field-scale $CO_2$ and $N_2O$ emission measurements of the year of 2019 and 2020 were published by Dencső et al., 2021 in Agronomy (Q1, IF:2,602).

Although this project has finished, there are still several manuscripts being currently written and expected to be published in the upcoming years, including manuscripts with international collaboration.

At the end of 2020 a manuscript was sent to Soil and Tillage Research (D1, IF:4.601 ) with the title of “Effect of tillage and crop type on soil respiration in a Central European long-term field experiment” with my last authorship. This Manuscript summarizes 5 year results of the tillage-experiment. The MS is still under review. In February, 2020 a two-authored manuscript was submitted to Water (Q1, IF:2.544) with the title of “Changes in the Soil-Plant-Water System due to Biochar Amendment”. In this study we investigated i) the changes in plant growth, ii) soil water and temperature at different depths, iii) $CO_2$ and $N_2O$ emissions after biochar application, and iv) the soil water, chemistry, and plant interactions. The MS got major review after the first evaluation. An other Manuscript is also ready to submit with my first authorship, with the title of: “Spatial mapping of soil respiration using auxiliary variables. A small scale study”. However modeling results has been only presented in this report till now, we would like to write a paper from these results as well.

## 7. Main changes in the project

The project was suspended from June 2016 till January 2018 because of maternity leave. During this period (with the institute support) emission measurements were continued by my PhD student and by some of my colleagues. Evaluation of the dataset started only in 2018. Also because of the Covid-19, the project was expanded till the end of February 2021.

There was a methodology change in $CO_2$ and $N_2O$ emission because two portable gas analyzers was bought by an other project. With these analyzers measurements became more precise and less time-consuming.

Although we overviewed plot scale-models also for $N_2O$ emission and chose the possible ones for our purposes, we couldn’t go further in modelling for until now. Regular $N_2O$ emission measurements were started in 2019, in the second year of the project, and in 2020 we measured $N_2O$ peaks only 3 times during the measurement period, although we measured this parameter in every second week. It confirms that $N_2O$ emission has high spatial and temporal variability and measuring it is a challenging issue. Even so, we had some success, since our dataset is used in development of the $N_2O$ and $CO_2$ modul AGROMO model (which is developed by Hungarian scientists). Also regular $N_2O$ emission measurements are unique in Hungary on arable land.

To find out how representative are our emission measurements for this field, we executed a heterogeneity analyses, in the no till and in the ploughing treatments which was not planned in work plan. In both treatments 150 sampling points were determined, where soil temperature, soil $CO_2$ emission, soil organic carbon content and soil water content were determined. After the first evaluation we concluded the soil $CO_2$ emission mostly depends on soil organic carbon and soil temperature in space, but no connection was found between $CO_2$ emission and soil compaction. Publication is planned from these results in the future.

## 8. References

Alvarez R, Russo M, Prystupa P, Scheiner J, Blotta L. (1998) Soil Carbon Pools under Conventional and No-Tillage Systems in the Argentine Rolling Pampa. *Agronomy Journal - AGRON J* **1998**, *90*, doi:10.2134/agronj1998.00021962009000020003x.

Bakacsi Zs, Laborczi A, Szatmári G, Horel Á, Dencső M, Molnár S, Ujj E, **Tóth E**. (2020) Compiling C/N and total-N dataset to support countrywide soil nutrient emission models for Hungary. STUDIES IN AGRICULTURAL ECONOMICS 122 : 2 pp. 86-95. , 10 p. (2020)

Baklanov Sz, Horel Á, Gelybó Gy, **Tóth E**, Dencső M, Ujj E, Potyó I. (2019) Különböző földhasználatú területek talajának nitrogénforgalmi vizsgálata változó hőmérsékleti értékeken. AGROKÉMIA ÉS TALAJTAN 68 : 79-96. , 18 p. (2019) Q3 MTMT [30703992]

Balashov E, Buchkina N, Rizhiya E, Farkas Cs. (2014). Field validation of DNDC and SWAP models for temperature and water content of loamy and sandy loam Spodosols. Int. Agrophys., 28:133-142.

Bogunovic I., Kisic I. (2017). Compaction of a clay loam soil in pannonian region of Croatia under different tillage systems. Journal of Agricultural Science and Technology, 19, 475-486.

Buchner J.S, Simunek J, Lee J, Rolston D.E, Hopmans J.W, King A.P, Six J. (2008) Evaluation of $CO_2$ fluxes from an agricultural field using a process-based numerical model. Journal of Hydrology, 361:131-143.

Chatskikh D., Olesen J.E., Hansen Elsgaard L, Petersen, M. (2008). Effects of reduced tillage on net greenhouse gas fluxes from loamy sand soil under winter crops in Denmark. Agriculture, Ecosystems and Environment, 128:117-126.

Dencső M, Gelybó Gy., Kása I., Horel Á., Farkas Cs., Birkás M., **Tóth E**. (2016a). Effect of agricultural management on soil carbon cycle. 2018a.Plant Biology Europe EPSO/FESPB, 2016.06.26. – 30. Prague

Dencső M, Baklanov Sz, Horel Á, Gelybó Gy, **Tóth E**. (2020) N2O emission and governing factors on arable fields. GEOPHYSICAL RESEARCH ABSTRACTS 22 Paper: 388 , 1 p. (2020)

Dencső M, Gelybó Gy, Kása I, Pokovai K, Potyó I, Horel Á, Birkás M, Takács T, **Tóth E**. (2017c) Effect of different management systems on soil CO2 emission and plant growth in a maize field. GEOPHYSICAL RESEARCH ABSTRACTS 19 Paper: 7727 , 1 p. (2017)

Dencső M, Gelybó Gy, Potyó I, Horel Á, Birkás M, **Tóth E**. (2018c) A talajrespiráció alakulása különböző talajművelési módok esetében In: Bakacsi Zs, Kovács Zs, Koós S (szerk.) Talajtani

Vándorgyűlés: Absztrakt és program füzet: Talajhasználat - funkcióképesség. 106 p. Konferencia helye, ideje: Pécs, Magyarország, 2018.08.29-2018.09.01. Magyar Talajtani Társaság, pp. 57-58. OA link; MTMT [3412359]

Dencső M, Gelybó Gy, Potyó I, Kása I, Horel A, Birkás M , **Tóth E** (2017b): Soil Respiration in a Long-Term Tillage Experiment. LOTEX, 2017, Nyíregyháza

Dencső M, Gelybó gy, Potyó I, Kása I, Horel Á, Birkás M, **Tóth E**. (2018a) Comparison of two methods for determining soil CO2 emission on an oat field. Geophysical Research Abstracts, Vol 20, EGU2018-6281, EGU General Assembly 2018. Bécs, Ausztria: 2018.04.09 -2018.04.13.

Dencső M, Horel Á, Bogunovic I, **Tóth E.** (2021) Effects of Environmental Drivers and Agricultural Management on Soil CO2 and N2O emissions. AGRONOMY 11 : 1 Paper: 54 (2021)

Dencső M, **Tóth E**, Gelybó Gy, Kása I, Horel Á, Rékási M, Takács T, Farkas Cs, Potyó I, Uzinger N. (2017a) Komposzt illetve műtrágya bioszén kezeléssel mutatott együttes hatásának vizsgálata karbonátos homoktalaj nedvességtartalmára talajlégzésére. Agrokémia és Talajtan 66 (2017) 1, DOI: 10.1556/088.2017.66.1.5

Dencső M, **Tóth E,** Horel Á, Potyó I, Birkás M, Gelybó Gy. (2018b) Evaluation of two methods measuring soil $CO_2$ emission in a tillage experiment. ISTRO 2018 2018.09.23. – 28, Paris, France

Dencső M., **Tóth E**., Gelybó Gy., Potyó I., Horel Á., Birkás M., Bakacsi Zs.(2019) Utilization of CRDS method in reactive trace gas emission estimation in agricultural experiments – preliminary results. GEOPHYSICAL RESEARCH ABSTRACTS 21 Paper: 16362 (2019) EGU General Assembly, Vienna, Austria,7–12 April 2019.

Dencső Márton, Gelybó Györgyi, Kása Ilona, Horel Ágota, Farkas Csilla, Birkás Márta, **Tóth Eszter**. 2016b. Különböző művelési módok hatása a talaj szénforgalmára. Talajtani Vándorgyűlés, 2016.09.01-09.03, Debrecen.

Drewer J., Anderson M., Levy P.E., Scholtes B., Helfter C., Parker J., Rees R.M., Skiba U.M., (2016). The impact of ploughing intensively managed temperate grasslands on N2O, CH4 and CO2 fluxes. Plant Soil. https://doi.org/10.1007/s11104-016-3023-x.

Farkas, Cs., Hagyó, A. 2010. Applicability of profile- and catchment-level mathematical model for evaluating the environmental effects of climate change. Klíma-21 Füzetek. 62. 59-74. (in Hungarian)

Gelybó Gy, Birkás M, Dencső M, Horel Á, Kása I, **Tóth E.** (2016) Soil respiration in a long-term tillage treatment experiment. GEOPHYSICAL RESEARCH ABSTRACTS 18 Paper: 14811 , 1 p. (2016)

Gelybó Gy, Dencső M, Potyó I, Kása I, Horel Á, Birkás M, Barcza Z, **Tóth E** (2018a**)**. Soil respiration in different tillage systems under crop rotation. Geophysical Reseach Abstracts, Vol 20. EGU2018-15206, 2018. EGU General Assembly 2018. Bécs, Ausztria: 2018.04.09 -2018.04.13.

Gelybó Gy, T**óth E**, Farkas Cs, Horel Á, Kása I, Bakacsi Zs. (2018b) Potential impacts of climate change on soil properties. AGROKÉMIA ÉS TALAJTAN, 67; 121-141. Q3 (2018) DOI: 10.1556/0088.2018.67.1.9; REAL: 85592; MTMT [3392635]

Gelybó Gy., Dencső M., Pozyó I., Kása I., Horel Á., Birkás M., Barzca Z., **Tóth E.** (2019) Five years of soil respiration measurements in two contrasting tillage treatments of a long-term field experiment. GEOPHYSICAL RESEARCH ABSTRACTS 21 Paper: 17285-1 (2019) EGU General Assembly, Vienna, Austria,7–12 April 2019.

Gelybó Gy., Kása I., Horel Á., Farkas Cs., Birkás M, **Tóth E**.(2015) Soil respiration and soil water regime in different land management systems. Proceedings of Peer reviewed contributions. 22nd International Poster Day and Institute of Hydrology Open Day. Transport of water, chemicals and energy in the soil-plant-atmosphere system. 2015:61-69. ISBN 978-80-89139-36-1.

Gupta H.V, Sorooshian S, P.O. Yapo. (1999) Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. J. Hydrologic Eng., 4(2), 135-143.

Hénault C, Grossel A, Mary B, Roussel M, Léonard J. Nitrous Oxide Emission by Agricultural Soils (2012). A Review of Spatial and Temporal Variability for Mitigation. *Pedosphere* 2012, *22,* 426-433, doi:https://doi.org/10.1016/S1002-0160(12)60029-0

Horel A, Bakacsi Zs, Dencső M, Farkas Cs, Gelybó Gy, Kása I, **Tóth E**, Molnár S, Koós S (2017). Eső hatása a Csorsza-patak vízgyűjtőjének téli hidrológiai folyamataira. AGROKÉMIA ÉS TALAJTAN 66:1 pp. 61.77., 17 p.

Horel Á, Potyó I, **Tóth E**, Gelybó Gy, Barna Gy, Dencső M (2018a). Soil $CO_2$ and $N_2O$ emission drivers in vineyard (Vitis vinifera) under different soil management systems and amendments. GEOPHYSICAL RESEARCH ABSTRACTS 20. EGU General Assembly. Bécs, Ausztria: 2018.04.09 -2018.04.13.

Horel A, **Tóth E,** Gelybó Gy, Baklanov Sz, Dencső M, Potyó I. (2019a). Soil $CO_2$ and $N_2O$ emission changes under different land uses and soil amendments. GEOPHYSICAL RESEARCH ABSTRACTS 21 Paper: 8322 (2019) EGU General Assembly, Vienna, Austria,7–12 April 2019.

Horel Á, **Tóth E**, Gelybó Gy, Dencső M, Farkas Cs. (2019b) Biochar Amendment Affects Soil Water and $CO_2$ Regime during Capsicum Annuum Plant Growth. AGRONOMY 9 : 2 Paper: 58 , 16 p. (2019) Q1 IF: 2.603MTMT [30413990]

Horel Á, **Tóth E**, Gelybó Gy, Dencső M, Potyó I: (2018b) Soil $CO_2$ and $N_2O$ Emission Drivers in a Vineyard (Vitis vinifera) under Different Soil Management Systems and Amendments. Sustainability, 10,1811; Q2, IF: 2.075 (2018) DOI: 10.3390/su10061811; REAL: 85655; MTMT [3385849]

Huang Y, Ren W, Wang L, Hui D, Grove J, Yang X, Tao B, Goff B (2018) Greenhouse gas emissions and crop yield in no-tillage systems: A meta-analysis. *Agriculture, Ecosystems and Environment* **2018**, *268*, 144-153, doi:10.1016/j.agee.2018.09.002

Hursh A, Ballantyne A, Cooper L, Maneta M, Kimball J, Watts J. The sensitivity of soil respiration to soil temperature, moisture, and carbon supply at the global scale. *Global Change Biology* **2017**, *23*, 2090-2103, doi:10.1111/gcb.13489.

Lognoul M, Theodorakopoulos N, Hiel M.P, Regaert D, Broux F, Heinesch B, Bodson B, Vandenbol, M, Aubinet M (2017) Impact of tillage on greenhouse gas emissions by an agricultural crop and dynamics of N2O fluxes: Insights from automated closed chamber measurements. *Soil and Tillage Research* **2017**, *167*, 80-89, doi:https://doi.org/10.1016/j.still.2016.11.008.

Maharjan G.R, Prescher A-K., Nendel C., Ewert F., Mboh C.M., Gaiser T, Seidel S.J. 2018. Approaches to model the impact of tillage implements on soil physical and nutrient properties in different agro-ecosystem models. Soil and Tillage Research, 180:210-221.

Moriasi D.N., Arnold J.G., Van Liew M.W, Bingner R.L., Harmel R.D, T.L. Veith. 2007. Model Evaluation Guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE, Vol 50(3), 885-900.

Nash J.E., J.V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. J. Hydrology 10(3): 282-290.

O'Dell D., Sauer T.J., Hicks B., Thierfelder C., Lambert D.M., Logan J., Eash N.S., 2015. A short-term assessment of carbon dioxide fluxes under contrasting agricultural and soil management practices in Zimbabwe. J. Agric. Sci. 7, 32–48.

Petersen B.M., Jensen L.S., Hansen S., Pedersen A., Henriksen T.M., Sorensen P, Trinsoutrot-Gattin, Berntsen J. (2005) CN-SIM: a model for the turnover of soil organic matter. II. Short-term carbon and nitrogen development. Soil Biology and Biochemistry, 37(2):375-393.

Pokovai K, Dencső M, Gelybó Gy, Potyó I, Horel Á, Birkás M, **Tóth E.** (2018) Növény növekedési vizsgálatok eltérő talajművelésű területeken. In: Bakacsi Zs., Kovács Zs., Koós S. (szerk.) Talajtani Vándorgyűlés: Absztrakt és program füzet: Talajhasználat – funkcióképesség. Magyar Talajtani Társaság, Pécs, 2018.08.28.-09.01. 93-94. (2018)

Pokovai K., **Tóth E**, Horel Á. (2020). Growth and Photosynthetic Response of Capsicum Annuum L. in Biochar Amended Soil. APPLIED SCIENCES-BASEL 10 : 12 Paper: 4111 (2020)
Saloranta, T., Kamari, J., Rekolainen, S., Malve, O. 2003. Benchmark Criteria: A Tool for Selecting Appropriate Models in the Field of Water Management. Environmental Management 32(3): 322-333.

Simunek J., van Genuchten M.Th., Sejna M. Hydrus (2012): Model use, calibration and validation. Special issue on Standard/Engineering Procedures for Model Calibration and Validation, Transactions of the ASABE, 55(4): 1261-1274.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C (2007) *Agriculture. In Climate Change 2007: Mitigation.*; Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

**Tóth E,** Dencső M, Gelybó Gy, Mészáros J, Bakacsi Zs, Horel Á, Josip Telak L, Galic M, Kisic I, Bogunovic I. (2020a) Spatial heterogenity of CO2 emission in Hungarian and Croatian arable fields-preliminary results. GEOPHYSICAL RESEARCH ABSTRACTS 2020 Paper: 19704 , 1 p.

**Tóth E,** Dencső M, Pirkó B, Bakacsi Zs, Koós S. (2020b).

**Tóth E**, Dencső M, Potyó I, Kása I, Horel Á, Birkás M, Barcza Z, Pokovai K, Gelybó Gy. (2018b) What governs soil respiration under different tillage practices? Geophysical Research Abstracts, Vol. 20, EGU2018-15498, EGU General Assembly 2018. Bécs, Ausztria: 2018.04.09 -2018.04.13.

**Tóth E.,** Dencső M., Birkás M., Gelybó Gy (2019). Tillage and mineral fertilizer effects on soil GHG emission in soil column experiment. In: Makádi, M (szerk.) LOTEX 2019: 2nd Conference on Long-term Field Experiments: book of proceedings. Nyíregyháza, Magyarország : University of Debrecen. Institutes for Agricultural Research and Educational Farm Research. Institute of Nyíregyháza, (2019) p. 117 , 1 p. (also oral presentation)

**Tóth, E**., Gelybó, Gy., Dencső, M., Kása, I., Birkás, M., Horel, Á. (2018a). Soil $CO_2$ emissions in a long-term tillage treatment experiment. 2018a. Chapter 19. In: R. Zornoza (Ed.) és M.A. Muñoz. Soil Management and Climate Change. Academic Press, pp: 293-307.

van Kessel, C.; Venterea, R.; Six, J.; Adviento-Borbe, M.A.; Linquist, B.; van Groenigen, K.J. Climate, duration, and N placement determine N2O emissions in reduced tillage systems: a meta-analysis. *Global Change Biology* **2013**, *19,* 33-44, doi:10.1111/j.1365-2486.2012.02779.x.
Van Waveren, R.H., Scholten, H., Van Geer, F. C., Wösten, J. H. M., Koeze, R. D., Noort, J. J. 2000. Good Modeling Practice Handbook. STOWA Report 99-05, Utrecht, RWS-RIZA, Lelystad, the Netherlands

Yeboah S, Zhang R, Cai L, Song M, Li L, Xie J, Luo Z, Wu J, Zhang J. Greenhouse gas emissions in a spring wheat–field pea sequence under different tillage practices in semi-arid Northwest China. *Nutrient Cycling in Agroecosystems* **2016**, *106,* 77-91, doi:10.1007/s10705-016-9790-1.